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Institutional Report

National Geophysical Research Institute (Council of Scientific & Industrial Research)

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The scientific knowledge of the Earth: its structure, dynamics, evolution, resources and natural hazards is paramount for survival and progress of mankind. The establishment of the National Geophysical Research Institute (NGRI) under the Council of Scientific and Industrial Research (CSIR), Ministry of Science and Technology, Govt. of India, in 1961, is an acknowledgement of importance that India ascribed to geophysics and allied disciplines. With a mandate for basic and applied research in Geosciences, NGRI made consistent and substantial advancements over the last fifty years evolving into an internationally acclaimed centre of excellence with truly multidisciplinary Earth science research programs that are aligned with the mission and the vision of the CSIR. Over the years, NGRI has acquired the necessary competence and facilities for multi-parametric data acquisition and interpretation. With about 150 scientists, nearly 400 technical and administrative staff and about 150 students and young researchers, the institute today has carved a niche for itself not only in Solid Earth Geophysics, but also in allied disciplines such as Geology, Geochemistry Geochronology, Geotechnical and Engineering Geophysics. The institute focuses on fundamental problems relating to Earth as a system with an emphasis on issues of societal and strategic relevance such as exploration for hydrocarbons and metallic ores, groundwater hydrology, earthquake hazard assessment, geo-environment, paleo-climates and climate change. A common theme in all these studies is to improve our ability to image deep and shallow parts of the Earth for its structure, composition and rheology, both spatially and temporally. During the last quadrennial period, NGRI recorded significant progress in many fields and also celebrated Golden Jubilee on October 11, 2011. During the period 2007-12, about 700 papers were published in SCI journals by the NGRI scientists. This report highlights some of the substantive contributions of the CSIR-NGRI and lists a brief selection of publications relevant to the points highlighted.

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Achievements and Contributions

Groundwater Exploration and Management

Between 2007 and 2012, the institute was nodal agency to a major networked R&D project on 'Groundwater hydrology' involving five other CSIR laboratories. Through this and numerous other R&D projects funded by the industry and different State Governments, the institute addressed a wide range of hydro geological issues of societal importance. The research themes comprised groundwater sourcing in hard rocks, desert, coastal and island regions of India, development and application of new geophysical, geochemical and isotopic approaches in: aquifer modelling; delineation of fresh and saline water interface in coastal regions; quantification of contamination and dispersal patterns of water in diverse ecological systems; water harvesting and sustainability of potable water and groundwater information system for farmers and policy makers. Some achievements are highlighted below:

A pilot study on strategies for revival of defunct minor irrigation tanks was successful in several drought prone areas such as the Chittoor district of Andhra Pradesh and was an example of scientific water harvesting that could be adopted by the State Government. The hydrologists and hydro-geochemists undertook newer challenges to monitor and trace the pathways of pollution related to a variety of situations ranging from Uranium, Chromium and coal mining to the impact of ash-dumps at thermal power plants, waste disposal at petroleum refineries, pharmaceutical industries and other urban centers. New insights include: i) New data on groundwater permeability conditions around tailing ponds associated with Uranium mining at Jaduguda and Turmadih, Jharkhand state; ii) Elucidation of the hydrogeological regime of Tadekeshwar lignite mine, Surat, Gujarat; iii) Methodologies for quantitative estimation of several drug molecules and toxic compounds including sulphonamides in the groundwater and sewage of Ghaziabad, UP; iv) Detailing of toxicity in groundwater at solid waste dumping sites, e.g., at Ghazipur; v) Water quality in the catchment areas of Hussainsagar lake, Hyderabad; vi) Assessment and mitigation strategy for chromium (VI) delineation of contaminated sites along the tannery belt of Ranipet, Tamilnadu and Sukinda Chromite mines, Odisha; vii) Study of Fluoride contamination in Nayagarh district, Odisha and Nalgonda district, A.P.

The source of geogenic Arsenic in ground waters in parts of Bihar and Jharkhand was traced to clay-rich beds in the alluvial soils, also high-resolution electrical methods were deployed to map the sub-surface succession of clayey and sandy layers to identify horizons that could be used for the extraction of Arsenic-free water from the sandy aquifers. The magnitude of toxic element pollution in water and soil at certain industrial establishments and appropriate mitigation strategies were addressed through large geochemical analytical data and the institute assumed leadership in conducting workshops to train scientists from the Pollution Control Boards of different states.

An important study pertains to the Jaisalmer region, Rajasthan, where radiocarbon dating of waters from a nearly 700m-deep aquifer indicated an unexpectedly ‘old age’ of about 40,000 years and indicated the possibility that this ‘heritage resource’ was poorly connected with the shallow aquifers in the region. The study prompted a discussion on whether such long-lived aquifers should be exploited.

A study encompassing the entire Indo-Gangetic Plains based on observational data from the Gravity Recovery and Climate Experiment (GRACE) satellite pointed out the alarming rate of water loss in northern India. This observation prompts a need for proper management strategies of water resources. On a macro-scale, direct estimation of temporal variations in groundwater levels and ways of optimizing water usage for agriculture formed the focus of a collaborative project with the Panjab Agriculture University.

A globally-accessible web-based Groundwater Information System has been developed by the NGRI. This has detailed layers of information on the groundwater level and quality with reference to major chemical species as well as information on the pesticide residues. This pilot project was supported by National Resource Data Management System, Department of Science and Technology with an objective of providing the above information at village-level ‘Knowledge Centres’ in the districts. Highly cultivated central parts of Punjab viz., old Amritsar and Jalandhar districts were chosen for the model study. This online system enables ready access of information to farmers about the status of groundwater conditions in a particular village with reference to the depths at which the groundwater is available and the quality of the potable drinking water in terms of major ion concentrations and persistence of pesticide residues.

Exploration for Minerals and Hydrocarbons

The CSIR-NGRI participated in detailed studies aiming to characterize the lateral and vertical extension of gas hydrates and free-gas across the Bottom Simulating Reflectors in the Makran, Kerala-Konkan and Krishna-Godavari (KG) marine sedimentary basins deploying high-resolution seismic reflection surveys. Analysis of variation of the seismic reflection amplitude with offset based on an appropriate rock physics model was insightful and interpretation of multi-channel seismic data in terms of a well-defined ‘effective medium model’ with micro-fractures helped in the quantification of gas hydrates in the KG basin. An integrated approach using different geophysical methods was used to map Mesozoic sediments beneath the Deccan basalt flows, a potential hydrocarbon source. The results indicate sediment thickness up to 2.0 km along the eastern part of the Deccan Volcanic Province.

Seismic, gravity and magnetic studies were carried out to aid the oil exploration programs in the country under National Exploration Licensing Policy blocks of Bikaneer-Nagaur, Brahmaputra and south Rewa basins. Several potential zones in Rajasthan, Gujarat, Assam, Andhra Pradesh, Uttar Pradesh and West Bengal were studied by surface geochemical exploration methods and potential targets for further intensive exploration were identified. A heli-borne Versatile Time-domain Electromagnetic System was deployed for Uranium exploration in the Singhbhum Shear Zone region of Bihar and Jharkhand and Proterozoic Chhattisgarh sedimentary basin under an arrangement with the Department of Atomic Energy-Atomic Minerals Directorate, Hyderabad. Seismic imaging studies were also undertaken in central India to trace Gondwana coal seams and sediments concealed under the Deccan basalt cover, and direct mapping of coal mine structures for coal-bed methane prospects. For instance, studies in the Ranigunj coal field led to the delineation of potential sub-surface zones for coal bed methane exploration.

Systematic efforts towards delineation of Gold, Nickel and PGE mineralization focused on the Cauvery Shear system of Tamilnadu, the Archean greenstone belts and gneisses of Andhra Pradesh, Karnataka, Central India, Uttar Pradesh and Rajasthan revealed new targets for further exploration.

Seismic Hazard Assessment

Research on Earthquake Hazard in different parts of the country has contributed to a range of significant results, such as, the importance of transverse tectonics in the Sikkim Himalaya, determination of a new velocity model based on waveform inversion of broadband data for earthquakes in the Koyna-Warna region (that gives a minimum residual error for the travel times), and quantification of seismic hazard in the central part of the Indo-Gangetic plains. Concerted efforts were initiated to augment the seismological and GPS network in the Andaman-Nicobar islands to monitor seismicity and deformation. Studies following the Sumatra Earthquake (December, 2004) suggested a return period of 400 years for another great earthquake in this region. Monitoring of seismic activity in northeast India and Garhwal Himalayas led to possible presence of large lateral velocity heterogeneities in the crust, and these accord with other models.

The last five years witnessed a new phase of high-resolution seismic studies, both active and passive in the Koyna-Warna region, which is a classic example of reservoir triggered seismicity (RTS). This involved deployment of a network of around 100 seismic stations for the monitoring of the local seismicity in addition to creation of 40 observation bore-wells to monitor closely the temporal changes in groundwater levels and measure a range of hydro-chemical parameters. Following the concept of nucleation of earthquakes of M<2.5, six moderate earthquakes (M 4-5) were successfully forecast during the last five years. Recent studies also demonstrated the utility of monitoring hydro-chemical and isotopic precursors in the region. Indeed, a prediction of $M \geq 5$ earthquake based on the observed trends in hydro-geochemical parameters, mainly Cl^-, SO_4^{-2}, F^- and $\delta^{18}O$, came true on December 12, 2009 with the occurrence of a 5.1 magnitude earthquake. This apparent success is encouraging and reinforces the scope for a variety of precursory measurements toward earthquake forecasting in RTS sites elsewhere.

New tsunami inundation models have been proposed for the west coast and parts of the east coast based on observational data on tsunamigenic waves in the past. These models will be relevant to the design of large irrigation and power projects and industrial sites along the coastline.

There has been an ever-increasing fascination toward palaeo-seismological studies at the NGRI and new attempts to establish the optical and radiocarbon chronologies at sites in the Himalaya provided data on the recurrence periods of major earthquakes.

A testing and calibration laboratory for accelerometers was established at NGRI and 40 accelerometers of ISRO, for application in space dynamics, were calibrated for application in space dynamics. Such facilities and the new networks of the Nuclear Power Corporation of India Ltd. (NPCIL) enable NGRI's R&D efforts to partner the nation's societal and strategic needs.

An important outreach activity, namely, the school earthquake laboratory program, was launched and 85 low-version seismographs were installed in schools spread over large regions of Assam and Maharashtra states. Teachers and students were appraised of basic concepts in seismology and on precautions during an earthquake.

Basic Research: Studies on the Lithosphere, Earth's Interior and Past Climates

A major project funded by the CSIR, the NGRI Supra Institutional Project, enabled continuation of basic research on the structure, dynamics, composition and the evolution of the Indian lithosphere. New data and significant results on a wide range of themes were obtained.

a) An integrated study on the Dharwar craton, southern India, involving coincident seismic reflection, refraction/wide angle reflection, long-period Magnetotelluric (LMT), broad-band Magneto-telluric, Deep Resistivity measurements (DRS) along the Perur-Chikmagulur transect (250 km long transect-1) and across the Chitradurga boundary fault sampling large parts of eastern and western Dharwar Craton was completed. In addition, an array of 55 broadband seismic stations comprising an extended teleseismic experiment alongside a campaign mode experiment of about 4000 new gravity measurements and petrological, geochemical and geochronological studies were carried out. These studies indicate that the crust of the Eastern Dharwar Craton, EDC (35-37 km) is thinner by about 7-10 km than that of the Western Dharwar Craton, WDC (45-47 km). The thickest crust around Hassan (WDC) is also the location of the thickest lithospheric keel. An important result from the reflection profile is the westward subduction of the EDC underneath the WDC in contrast to the eastward subduction models in the literature. The new data also provides clear evidence for distinct crustal and lithospheric character of the WDC and the EDC. The most conspicuous observation is the absence of a high velocity mafic lower crust (>7 km/sec.) in EDC in contrast to WDC, implying either de-lamination of a previously thickened EDC or accretion of two distinct lithospheric blocks along the eastern boundary of the Chitradurga greenstone belt during the late Archaean (2.7-2.5 Ga).

b) New seismic reflection profiling and deep resistivity sounding results lend credence to a tectonic subdivision across the eastern boundary of the Chitradurga schist belt. A trans-lithospheric suture zone between WDC and EDC gains support from major and trace element modelling of garnet xenocrysts from 1.1 Ga kimberlites. Thus, the Late Archean tectonics in the craton mimic modern arc-type accretion, thickening and de-lamination. New evidence for unusual crustal thicknesses reaching 65 km along the southern and western fringes of the WDC is fascinating. There is evidence for a large topographic relief of the lithosphere-asthenosphere boundary (LAB), between 220 and 100 km underneath the Dharwar craton supporting complex attrition and survival of cratonic roots. Modelling of heat flow observations together with shear wave velocity and petrochemical results suggest that the upper mantle of the EDC could be relatively Fe-enriched than the WDC and other cratons elsewhere. New U-Pb zircon geochronology and geochemistry reveal the juvenile nature of the oldest known, 3360 Ma tonalities in the WDC. High precision U-Pb baddeleyite age determinations and palaeomagnetic signatures on several mafic dyke swarms in the Dharwar craton have established 2367 Ma and 2210 Ma regional dyke emplacement events suggesting existence of large igneous provinces at these times.

c) In a major contribution to the understanding of Southern Granulite Terrain (SGT), a 2-D velocity depth model from wide-angle seismic refraction studies along a 140 km transect in the northern part of the SGT, revealed the deep-structure of the crustal-scale Cauvery shear zone system. Additionally, deep seismic profiling of the southernmost part of the SGT revealed the sub-crustal structure of Achankovil lineament and the adjacent terranes of Madurai and Trivandrum blocks. A case for Neoproterozoic ophiolites is made from new geological and compositional data sets on the Cauvery Shear Zone. Integrated models attempt to rationalize the new data sets in terms of Neoproterozoic-early Cambrian collision tectonics and crustal accretion as a part of the grand picture of Gondwana amalgamation.

d) Important aspects of the Indian lithosphere, such as, the mechanical coupling between the crust and upper mantle beneath the Himalayan and Peninsular regions of India have been described in terms of a new dataset on seismic anisotropy, which has implication on the India-Eurasia continental collision. Seismic tomography of the Indo-Tibetan collision zone revealed slow Tibetan mid-crust and low sub-Moho velocities beneath the central and north-eastern Tibetan Plateau. High resolution imaging of the crust and upper mantle regions of the eastern Himalaya and southern Tibet provided new insights into the nature and geometry of the underthrusting Indian plate. Fine scale variations in the shear structure of the Indian crust along the Himalayan arc appear to correlate with the pattern of earthquake occurrence. Using data from a dense network of open source, the northern limit of the Indian plate has been traced further south of the Bangong-Nuang suture zone, contrary to previous understanding. Also, the transition zone (660–410km) structure underneath these regions brings out new evidence for remnant lithospheric fragments resulting from detachment of thickened roots due to gravity removal.

e) New Sr, Nd and Pb isotopic results on several alkaline intrusions within the Gondwana basins suggest temporal, spatial, and genetic affinity with 116 Ma old Rajmahal and Sylhet Large Igneous Provinces and the Kerguelen plume.

Studies on investigation of mantle plumes and their depth of origin through seismic tomography and receiver function analysis suggested plume origins from the core-mantle boundary that has distinct seismic signatures. A study of shear wave anisotropy of the Godavari rift zone ascribes the observed anisotropy to either active rifting and attendant asthenospheric flow or passive rifting and, suggests lithosphere thinning due to far field stresses.

In summary, the multi-disciplinary data sets obtained in recent years have enabled many important generalizations on the nature of the Indian lithosphere and its evolution through its ~3600 Ma geologic record. Some interesting observations and results are:

(i) The evidence for a thin (~100 km) Indian lithosphere manifest in its rapid drift during the Phanerozoic,

(ii) Recognition of an anomalously thick crust beneath Tibet,

(iii) Conceptualization of terrane accretion through identification of crustal-scale shear zone systems as piercing points in the reconstruction of India in Gondwana,

(iv) Identification of the signatures of ancient subduction in the lithosphere and the Mantle Transition Zone underneath the Proterozoic mobile belts and the Himalaya,

(v) New evidence for late Archaean plate tectonics in Dharwar Craton via contrasting nature of the sub-continental lithospheric mantle across the western and eastern cratonic nuclei.

(vi) Modes for Indian plate motion and quantification of active fault movements through GPS and INSAR.

Other Significant Contributions

a. Contribution to India's strategic requirements in terms of redefining an extended legal continental shelf beyond 200 nautical miles for the country through systematic geophysical exploration. This has added several thousand square kilometers of resource potential for India as per UNCLOS guidelines.

b. Revised Gravity Map Series on 1:2 million scale with 5 mGal contour interval based on 52,000 gravity observations sampled at 3-minute arc interval. This was in collaboration with GSI, ONGC, OIL and SOI.

c. Magneto-telluric studies in the Puga valley of Jammu & Kashmir suggest the presence of an anomalous 4-5 km thick geothermal reservoir at a depth of 1.5 km

Major R&D Facilities at the NGRI

1. Airborne Geophysics:

Magnetic, radiometric and electromagnetic (frequency and time domain) facilities for multi-parametric heli-borne geophysical surveys for mineral exploration.

2. Deep Earth Probes:

High fidelity controlled source seismic instrumentation together with broadband seismic units for campaign mode investigations, magnetotelluric and deep resistivity probes, absolute micro-gravity and field gravity stations and magnetometers.

3. Shallow Surface Geophysics:

3D Seismic Data Acquisition System with Mini Vibrator, Induced Polarization and frequency/time domain EM equipment, Ground Penetrating Radar (GPR), high resolution gravity, magnetic instruments.

4. Seismological Observatory:

Broadband (120s-50Hz) Seismological Observatory, Regional networks covering northeastern India, Peninsular India and Andaman Islands for continuous earthquake monitoring in real time.

5. GPS/GNSS, Geodetic Network:

Network of GPS stations linked to international arrays for study of the Indian plate motion and applications for tectonic geodesy.

6. INTERMAGNET Magnetic Observatory:

Continuous mode recording of fluctuations of the geomagnetic field and near real time space weather observations.

7. Geothermal Observatory:

Measurement of air temperature, relative humidity, solar radiation, precipitation, wind speed, direction and subsurface temperature variations up to a depth of around 30 m, for climate change applications.

8. Geochemical Analytical Facilities:

Fully automated X-ray fluorescence spectrometer, Atomic absorption spectrometer, Laser ablation-inductively coupled plasma mass spectrometer, Electron probe micro analyzer and Scanning electron micro probe for bulk and *insitu* compositional analysis of natural materials.

9. Geochronology and Radiogenic Isotope Analytical Facilities

Thermal Ionization Mass Spectrometer, Multi Collector-Inductively Coupled Plasma Mass Spectrometers and Laser Ablation M-ICPMS for Rb-Sr, Sm-Nd, K-Ca, Pb-Pb and in-situ U-Pb zircon geochronology.

10. Stable Isotope Laboratories

Gas source mass spectrometers, GCMS-MS, element samplers and analyzers supporting T, H, O and C-isotopic studies for applications in isotope hydrology, hydrocarbon exploration, study of paleo-climates and geo-environment.

11. High-pressure experiments for rock mechanics and engineering geophysics applications.

12. Indo-French Centre for Groundwater Research.

13. Advanced Computing Facility for Geodynamo simulations, and

14. LAM-MC-ICPMS National Facility.

An Outlook for the Future

One of the primary focuses of future research at CSIR-NGRI would be to enhance its expertise in quantitative data analysis and interpretation. Large scale numerical simulation and inverse modelling techniques will be used to obtain high resolution subsurface images together with an estimation of uncertainties. A centralized computing system for easy access of several datasets for analysis shall be established.

A new project called INDOSCOPE to systematically image the Indian lithosphere is being initiated. Other major projects proposed for the next five years include: (1) detailed aquifer mapping and ground water management in Krishna-Godavari river basin, (2) seismic hazard estimation in densely populated regions and sites of strategic importance, (3) technology development for exploration of conventional and non-conventional hydrocarbon and mineral resources. Thus, the focus shall be on basic research on themes of societal relevance.

Significant Publications

Groundwater Exploration Management

Krishna, A.K., Satyanarayanan, M. and Govil, P.K., 2009. Assessment of heavy metal pollution in water using multivariate statistical techniques in an industrial area: A case study from Patancheru, Medak district, Andhra Pradesh, India: Jour. Hazardous Materials, v. 167, p. 366-373.

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